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Practice Note 28
Screw Piles: Guidelines for Design, Construction & Installation

Engineering Practice

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Preface

The purpose of the *Practice Note Screw Piles: Guidelines for Design, Construction and Installation* is to highlight many critical elements of the design, installation and testing of screw piles. It provides recommendations for good practice in New Zealand, and should be used as a technical reference to inform engineers, developers, contractors and local authorities.

Practice Note Development

This Practice Note has been facilitated by the Institution of Professional Engineers New Zealand (IPENZ), with support from principal sponsors Piletech, and authorship provided by Beca Ltd.

The IPENZ Engineering Practice Advisory Committee has given the lead author the task of preparing a document to be adopted by the engineering industry that reflects a national perspective.

The Practice Note has been prepared in accordance with standard IPENZ Practice Note procedures, which includes reporting on progress to the Engineering Practice Advisory Committee, peer review and general Membership review. This review and reporting process ensures the delivery of a robust, good-practice technical document.

Acronyms

AS	Australian Standard
B1/VM4	New Zealand Building Code, Structure Foundations, Verification Method
BCA	Building Consent Authority
CPT	Cone Penetrometer test
CHS	Circular Hollow Section
D	Helix Diameter
IANZ	International Accreditation New Zealand
IPENZ	Institution of Professional Engineers New Zealand
LPILE and GROUP	Software program for analysing either single or pile groups under lateral loading
MBIE	Ministry of Business, Innovation and Employment
NDT	Non-destructive testing
NZGS	New Zealand Geotechnical Society
NZS	New Zealand Standard
PS1	Producer Statement Design
PS2	Producer Statement Design Review
PS-C	Producer Statement – Construction
PS4	Producer Statement Construction Review
SLS	Serviceability Limit State
SPD	Screw Pile Designer
SPT	Standard Penetrometer Test
ULS	Ultimate Limit State
t	Tonne

Glossary

Bearing capacity	The capacity of the soil to resist load
Cohesive soil	A sticky soil such as clay or clayey silt having a strength that depends on the surface tension of capillary water
Cohesionless soils	Any free-running type of soil such as sand or gravels having a strength that depends on the friction between particles
Compression capacity	The maximum amount of downward force (from the load of the structure or soil) that a screw pile can resist before failing (may be limited by either the geotechnical capacity of the soil or structural capacity of the pile).
Deflection	Movement of the installed pile in either – or both – the lateral or vertical plane(s)
Founding layer	The layer of soil in which the helix plate is seated (also called the 'bearing layer').
Founding level	The exact place or level where the lower plate of the bearing helix sits
Installation torque	The rotating force required to install the screw pile into the ground
Lateral capacity	The maximum amount of horizontal force that a screw pile can resist, such as earthquake shear loads before failing (may be limited by either the geotechnical capacity of the soil or structural capacity of the pile).
Negative skin friction	The downward movement of a pile as a result of soft or liquefiable soils producing a down drag as they compress from an additional load. (For design purposes NSF can either be taken either as an addition to structural capacity requirements or as a reduction in geotechnical capacity.)
Punch through	Excessive downwards deflection of the pile seat (under compression) into a weaker soil below when the geotechnical capacity of the stronger, but relatively thin, founding layer is exceeded.
Sensitive soils	Soils that have a high loss of strength following a disturbance, such as volcanic ash or highly-weathered ignimbrite
Soil consolidation (settlement)	Lowering of the ground surface over time following deformation (over time) of a weak soil layer beneath when pore water pressures (generated after structural loading) have dissipated.
Strength reduction factor	A factor (of less than one) that provides a margin of safety to reduce the risk of failure applied to the ultimate soil capacity or pile capacity to cover variations and uncertainties.
Tension capacity	The maximum amount of upwards pulling force that a screw pile can resist before failing (may be limited by either the geotechnical capacity of the soil or structural capacity of the pile).
True helix	A helix having perfect symmetry with a uniform pitch all round and parallel leading and trailing edges
Undrained shear strength	The maximum amount of shear stress that may be placed on a cohesive soil before it yields or fails.

Contents

1. Introduction

Screw piles are a type of foundation system now widely used in the construction industry. They can offer significant advantages in terms of speed and ease of installation and by offering a reduction in the offsite disposal of drilling spoil.

New Zealand has recently seen a substantial increase in their popularity, especially following the 2010/2011 earthquakes in Christchurch. The Australian Standard *AS 2159 Piling Design and Installation* [1] can be used as a guideline in the design,testing and installation of screw piles and is referred to extensively in this Practice Note. However, the lack of any published New Zealand code of practice means that significant reliance is placed on individual practitioners to ensure that piles meet the performance requirements of each structure. An increasing number of designers and installers find themselves having to work within a largely unregulated marketplace.

Concerns have been expressed that New Zealand might experience similar problems to those encountered in Australia a decade ago when the evolution of screw piling technology saw large numbers of practitioners entering a market where standards were not well defined. This lack of standards and Codes of Practice resulted in performance issues and litigation. Adding to these concerns is the fact that any issues with screw pile designs are unlikely to present themselves until the piles experience significant additional loadings, such as during a large seismic event.

This Practice Note highlights many critical elements of the design, certification, installation and testing of screw piles. It provides recommendations for good practice in New Zealand, and should be used as a reference to inform engineers, developers, contractors and local authorities.

Piletech, a specialist designer, supplier and installer of screw piles, has led the way in establishing the screw pile market in New Zealand and has sponsored the writing of this Practice Note.

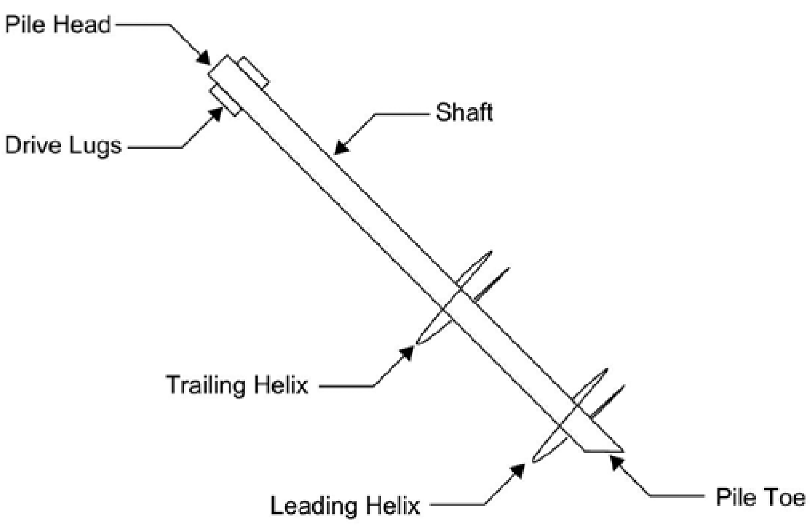
2. Overview of Screw Pile Technology

2.1 What is a screw pile?

Screw piles are a type of piled foundation, or retaining wall anchor, that have been in use since the 1830s. They are made of circular hollow steel sections with one or more helices welded to the shaft that provide a self-tapping mechanism during installation. The hollow stem may be filled with reinforced concrete following installation and is structurally connected to the building substructure.

Shaft diameters range from 50mm up to 600mm and helix diameters range from 150mm up to 1200mm depending on capacity requirements.

Figure 2.1: Components of a Screw Pile



2.2 Applications of Screw Piles

Screw piles are an option where the ground near the surface is, or has become too weak, to support a structure. Screw piles can also be used where the shape, size and location of the structure cannot be supported by alternative foundation methods.

Screw piles can be used for the following:

New foundations

Support to new structures including:

- residential, commercial and industrial buildings
- bridges, wharves and jetties
- transmission towers and wind turbines
- transportable buildings
- signal gantries
- pipes.

Re-levelling and Strengthening Existing Foundations

- permanent or temporary support for re-levelling of existing structures that have settled
- seismic/gravity capacity improvements
- responding to building damage from hazards such as earthquakes, particularly in constrained work areas and around existing structures, (as shown in Figure 2.2)

Anchoring

- permanent support for new or existing retaining structures,
- slope stabilization and slip remediation (shown in Figure 2.3), particularly if it is required in a short time frame
- temporary anchoring of machinery particularly against uplift. Piles can be removed and reused.

Pile Load Testing

- as an alternative to the Kentledge system of weights (load testing using pre-cast concrete blocks or steel plates), especially when large forces are required.

Figure 2.2: Screw Piles used for Re-levelling and Strengthening existing Foundations after Quake Damage

Figure 2.3: Screw Piles used for Anchoring

2.3 How screw piles are installed

Screw piles are wound into the ground, much like a wood screw. The helices cut into the soil following a constant pitch, as opposed to auguring through it. The helical flights and shafts are specifically shaped and designed to suit the ground conditions.

Hydraulic powerheads are used to apply the large torque that is required to screw a screw pile into the ground.

The powerheads are fastened onto handling machines that range in size from ½ tonne Bobcats, 20 tonne Excavators, and up to 100 tonne mast mounted crane rigs. The combination of hydraulic powerhead and handling machine required is determined by:

- Installation torque requirements
- Torsional capacity of the shaft
- Site access limitations (height/width/clearance to obstructions)
- Soil profile and site ground conditions
- Positional tolerances.

For permanent applications once the pile has reached the target depth the shaft is typically filled with concrete. In some cases this can increase the capacity of the pile. Embedded and protruding reinforcing, or using a top plate, provides a connection to the building structure above.

Because screw piles can be easily installed and removed they are often used in temporary situations.

3. Advantages, Disadvantages and Suitability of Screw Piles

During the option evaluation and detailed design stages, it is important to understand the relative advantages, disadvantages and suitability of screw piles as pile foundations or anchors.

3.1 Advantages

- Shorter set-up and installation times that need less labour than other pile options, with some specialised machines only requiring one certified installer
- Easy to extend and splice in-situ
- Simple to remove if required for a temporary situation with no damage to the screw pile, enabling re-use
- Possible to install in areas with poor accessibility, for example, where there is low headroom or other types of confined spaces
- Can be installed at an inclination, primarily for anchoring slopes
- Minimal vibration and construction noise during installation compared to other pile methods – important when putting in foundations near vibration and noise sensitive structures or underground services
- Can be installed in almost any climatic condition (only the most extreme ground temperatures or atmospheric weather conditions will affect proper installation)
- Reduced disposal costs, particularly where ground is contaminated, due to very little spoil created by the helix during installation
- Can be loaded (including for load testing) immediately after installation (unless concrete setting time is required after infilling)
- Installation torque provides an indication of ground strength at each pile
- Temporary supports, such as casings, are not required in soft or unstable ground.

3.2 Disadvantages

- The lack of soil produced post-installation prevents the confirmation of founding materials
- The relatively narrow shaft diameter may compromise capacity in the event of large (seismic) lateral loads or overturning moments
- Obstructions or hard layers may prevent embedment of the screw pile
- Soil corrosion factors may limit life (as with all buried steel piles).

3.3 Suitability of screw piles in certain ground conditions

Hard rock

Installing into hard rock can result in spin without penetration forming a void below the helix (or helices) and displacement of material above the helix. If the hard rock cannot be penetrated, alternative solutions will need to be found such as using high penetration heads, changing to conventional bored piles or grouting the seat of the pile toe.

Screw piles are best suited to ground conditions with gradually increasing soil strength or where there is a gradual weathering profile at the top of the rock. In these conditions it is much more likely that the helix will be fully seated, that is, the full face (lower surface) of the helix will be in contact with the founding layer. Where soft soils overlay hard rock it may not be possible to fully seat the helix and there is a risk that the helix plate will buckle.

Weak and/or liquefiable soils

Screw pile shafts are generally more slender than other types of pile foundation making them more prone to buckling in poorly supporting soils. When piling is required through deep deposits of weak soils and/or liquefiable soils, such as peat, very loose sands, and soft clay, there is an increased risk of shaft buckling.

Screw piles, or indeed any other type of deep pile, are considered unsuitable for sites with the potential for major lateral spreading (>300mm) originating from deep and thick liquefiable layers, or for sites without any dense non-liquefiable bearing layer.

Layered soils

If weaker soils are present either immediately above or below the helix position at founding level (once installation has been completed) installation torque values may indicate a greater pile capacity than that actually available. Monitoring of torque during installation for the last 3D in depth prior to founding may be required to verify the strength of the material immediately above the helix to ensure tension capacities (see Section 6.5).

Either Cone Penetrometer tests (CPT) or boreholes extending below the founding level are recommended at critical pile locations to confirm that ground beneath the helix is competent.

Sensitive soils

Large pile deflections may occur in highly sensitive soils when resisting uplift forces. This is due to the potentially disturbed soil matrix above the helices. In such soils the displacement tolerances of the structure to be supported will become a critical factor in the foundation design.

Soils with obstructions

Precise placement of screw piles in soils with a variety of large particle sizes, such as very gravelly soils or boulders may not be possible. In this situation, positional tolerances with respect to the structure and load transfer into the pile cap will be a critical design factor.

4. Factors Influencing Screw Pile Capacity

Geotechnical conditions and the structural design of the screw pile affect pile capacity. Screw piles are designed so most of the capacity of the pile is generated through the bearing of the helix plates against the soil rather than shaft friction. This is why ground conditions and the pile design itself are important.

A number of factors affect pile capacity. These are listed below and discussed in more detail in Section 6 (Geotechnical Factors in Determining Screw Pile Capacity) and Section 7 (Screw Pile Structure Design):

- Types of soils and their engineering properties
- Depth, thickness and the strength of soil overlying and underlying the founding layer
- Whether the load is compression, tension, lateral or a combination
- Choice of strength reduction factors
- Screw pile design and manufacture:
  - Shaft size
  - Number of helices
  - Size and spacing of helices
  - Concrete in-filled or not
  - Helix-to-shaft weld
  - Quality of "true helix" form
- Pile spacing and installation angle
- Installation torque
- Structure to pile deflection tolerance
- Structure to pile connection.

5. Geotechnical Investigation Requirements for Screw Pile Foundations

Appropriate geotechnical investigations must be carried out on all sites to determine the ground conditions and enable identification of potential issues such as the presence of obstructions, hard rock, liquefaction, instability, and corrosiveness of soil/groundwater.

The number of investigation locations will vary and will be greater where ground conditions are expected to be highly variable or when there are larger, more complex foundation requirements. Any investigations for screw pile design should extend below proposed founding depths to confirm the adequacy of the proposed founding material. See Appendix A: Considerations for Geotechnical Investigations for Screw Piles for a summary of considerations when determining the scope of site investigations for screw pile design.

Field classification and description of soil and rock should be undertaken in accordance with the *New Zealand Geotechnical Society (NZGS) Guideline for Field Description of Soil and Rock* [2].

At the time of writing this Practice Note (October 2015) the Ministry of Business, Innovation and Employment (MBIE) and the NZGS are preparing practice advisory notes and specific guidance on geotechnical investigations. These documents should be referred to when published.

Key Point

All projects must have adequate site specific geotechnical investigations that extend to depths well below the proposed pile founding level.

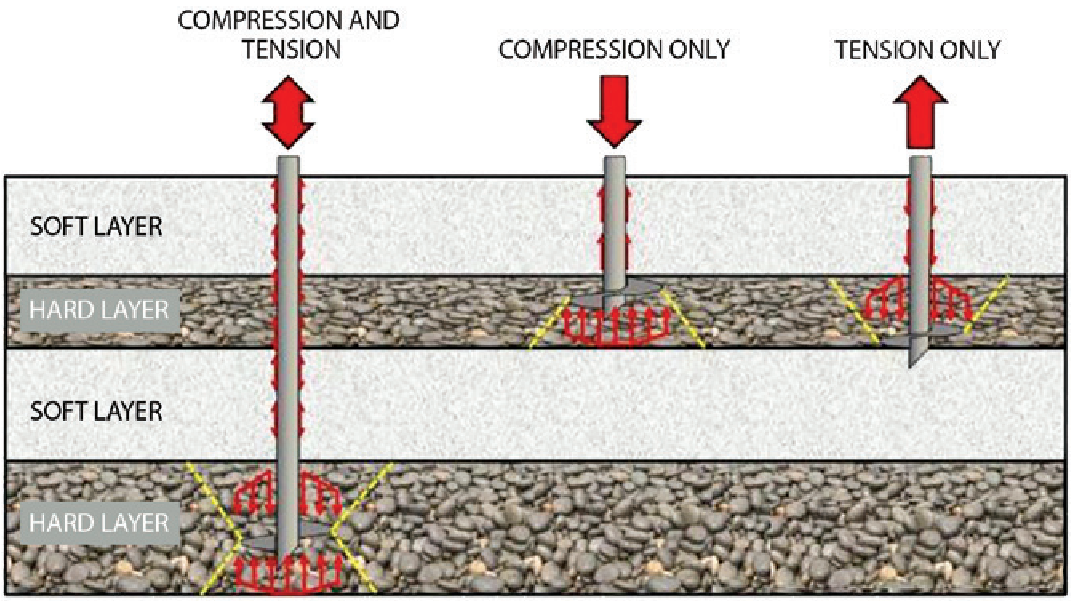
6. Geotechnical Factors in determining Screw Pile Capacity

Screw piles can be used in compression to support structures transferring loads through weak or liquefiable soils to harder soils or rock, and in tension to resist uplift loads from structures and provide support to retaining structures. In most situations the installed screw pile will have both compression and tension loads.

Figure 6.1 shows various load paths in a layered soil profile

- A screw pile carrying both compression and tension loads needs to be founded deeper below weaker/softer/ liquefiable soils
- A screw pile under only compression loading needs to have adequate thickness of hard soil beneath the helix to prevent punching failure (see Section 6.2) and pile deflection (see Section 6.6)
- A screw pile under only tension loading requires an adequate thickness of hard soil above the helix to reduce risk of pull-out (see Section 6.3).

Figure 6.1: Simplified Load Paths



There are a number of key geotechnical factors that need to be taken into consideration when designing for screw pile capacity:

- Seismic actions
- Compression capacity in coarse grained (cohesionless) and fine grained (cohesive) soils
- Tension capacity
- Lateral capacity
- Capacity derived from installation torque
- Pile deflection
- Pile spacing
- Strength reduction factors.

6.1 Seismic considerations

New Zealand is a high earthquake hazard region and, as such, the effects of earthquake shear loads are an integral consideration in the design of the built environment. Factors for effective seismic design include:

- classification of Site Subsoil Class in accordance with *AS/NZS 1170 Structural Design Actions* [3]
- assessment of the potential for, and effects of, liquefaction, cyclic softening, lateral spreading and land sliding. Guidance on liquefaction assessment is given in the *NZGS Guideline "Geotechnical Earthquake Engineering Practice – Module 1 – Guideline for the identification, assessment and mitigation of liquefaction hazards"* [4] and in *MBIE's "Guidance: Repairing and rebuilding houses affected by the Canterbury Earthquakes"*[5].

Residual soil strengths which affect compression capacity (Section 6.2), tension capacity (Section 6.3) and lateral capacity (Section 6.5) of the shafts, should be assessed in accordance with the guidance in [4] and [5].

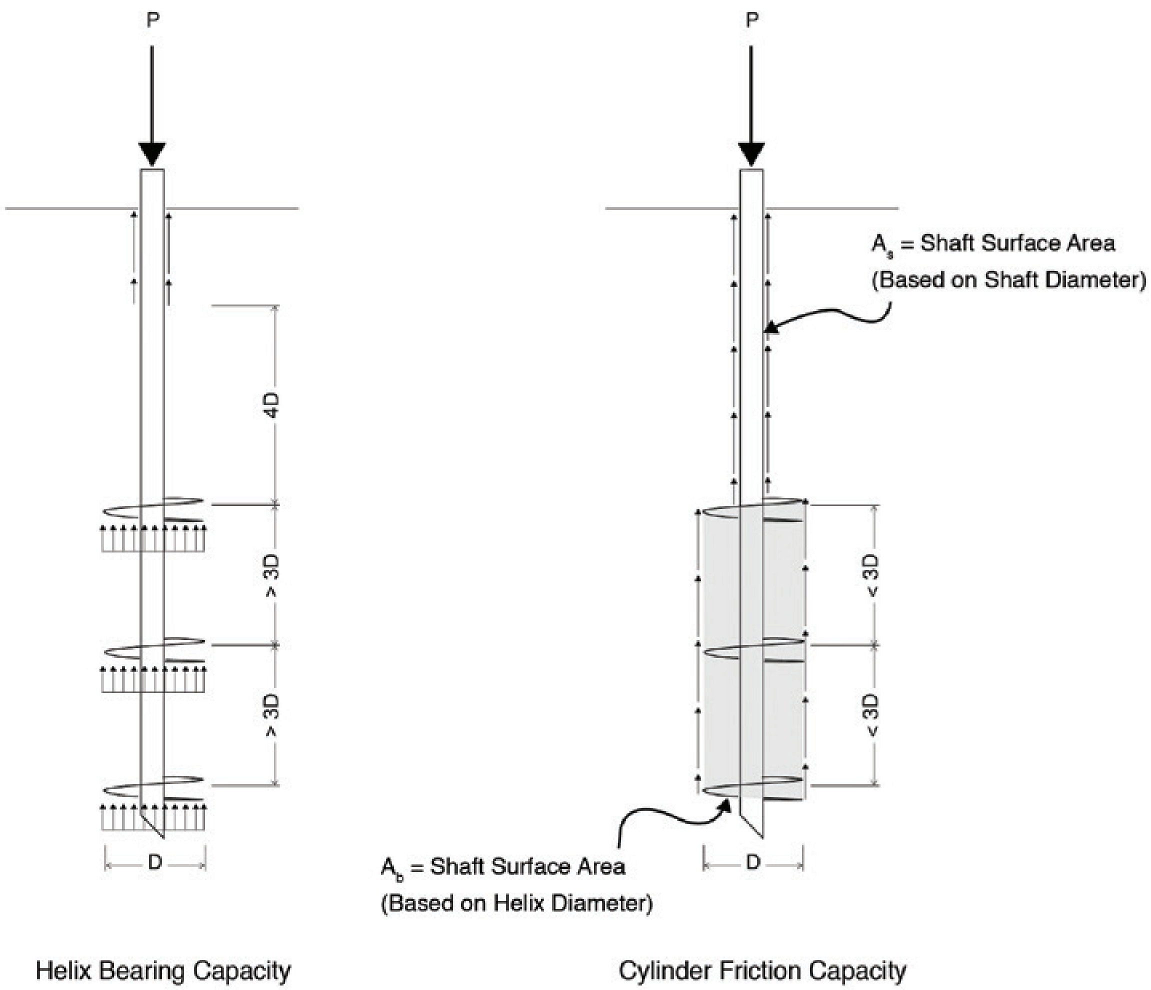
Where potentially liquefiable layers exist the suitability of screw piles will need to be assessed. Further particular considerations needs to be given to the suitability of screw piles being used at an inclination (rake) in such ground conditions.

6.2 Compression capacity

Figure 6.2 illustrates the elements used in determining theoretical screw pile capacity. Due to the composite parts of a screw pile compression capacity is comprised of two elements:

- Cylinder Friction Capacity
- Helix bearing capacity.

Figure 6.2: Cylinder Friction Capacity and Bearing Capacity (*HelixPile* [6])



The primary origin of screw pile capacity is the bearing capacity of each helix plate. Where there is more than one helix, the spacing of the helices on the shaft is fundamental to the total capacity of the screw pile. For maximum capacity this will occur at helix spacings greater than 3D. *Clayton, Basic Helical Screw Pile Design* [7]).

Section 6.2.1 and 6.2.2 show how theoretical compression capacities of screw piles for coarse grained and fine-grained soils are derived. (Theoretical capacities based on 'effective stress methods' as suggested below may only apply for pile lengths of up to 20D, *Tomlinson and Woodward, Pile Design and Construction* [8].)

6.2.1 Coarse Grained Soils

The theoretical ultimate capacity should be the smaller of:

- The sum of the helix bearing capacities (if widely spaced helices) plus shaft friction capacity (from 4D above the helix)[1]; or
- The sum of the base helix capacity plus helix cylinder friction capacity (if closely spaced helices) plus the shaft friction capacity.

Table 6.1 describes the factors involved in deriving screw pile capacity in coarse grained soils.

Table 6.1: Screw Pile Capacity in Coarse Grained Soils

Helix Bearing Capacity	Cylinder Friction Capacity
Helix Bearing Capacity = $\sigma_v{}' N_q A_B$	Shaft Friction Capacity = $k\,\sigma'_{vaverage} \tan\sigma A_s$ Helix Cylinder Friction Capacity = $k\,\sigma'_{vaverage} \tan\phi A_b$* *Assumes more than one helix spaced less than 3D apart
• $\sigma_v{}'$ = Vertical effective stress at helix level • N_q = Bearing capacity factor • A_B = Surface area helix base plate[2] The total capacity is derived by summing the capacities of all the plates. N_q is a function of embedment depth in the founding layer Capacity should be determined using the soils 5D above and below the helix.	• K = Coefficient of horizontal stress • $\sigma'_{vaverage}$ = Average vertical effective stress between helices or along the shaft • ϕ = Soil friction angle • σ = Interface friction angle = 2/3ϕ • A_s = Shaft surface area • A_b = Shaft area based on helix diameter *ϕ can vary for different soils from 24° to 38°

1 The Influence of the bearing up the shaft needs to be taken into consideration. Only the component of the shaft capacity higher than 4D above the highest helix should be used.

2 The base resistance is limited by the bending strength of the helix which is determined by the plate thickness, the outstands from the shaft and the yield strength of the steel (see Section 7.3.2).

6.2.2 Fine grained soils

The theoretical ultimate capacity is derived in the same method as for coarse grained soils but some parameters are different (see Table 6.2).

Table 6.2: Capacity in Fine Grained Soils

Helix Bearing Capacity	Cylinder Friction Capacity
Helix Bearing Capacity = $N_c Cu A_B$	Shaft Friction Capacity = $\alpha C_u A_s$ Helix Cylinder Capacity = $\alpha C_u A_B$ *Assumes more than one helix spaced less than 3D apart
• N_c = Bearing Capacity Factor • C_u = Undrained shear strength at helix level • A_B = Surface area helix base plate Total capacity is derived by summing capacities of all the plates. C_u should be determined using the soils 5D above and below the helix. N_c is a function of embedment depth in the founding layer	• α = Adhesion factor • C_u = Undrained shear strength along shaft or between helix level • A_s = Shaft surface area • A_b = Shaft area based on helix diameter

Compression capacity modifiers

Liquefaction

Liquefaction reduces compression capacity. The extent and cause of the reduction is dependent on the position of the liquefied soil relative to the founding layer [4]:

- If the liquefiable layer is directly below the proposed founding layer the reduced capacity is due to the lowered bearing capacity generated by the helix into a weak soil
- If the liquefiable layer is above the founding layer reduced capacity will be due to negative skin friction.

Thin strong layer over a weak layer

Where piles are founded in a thin strong layer overlying a weak soil layer and the load exceeds the capacity of the weak underlying layer, the likelihood of "punching" into the weaker layer needs to be assessed.

To minimise the likelihood of punching it is recommended that the thickness of the founding layer beneath the lowest helix should be at least five times the helix diameter, 5D[3].

Deflection and Soil Disturbance

A reduction in capacity may need to be applied to account for the effects of soil disturbance due to installation and/or deflection of the pile (see Section 6.6).

> **Key Point**
>
> Theoretical design capacities should be considered an upper bound unless actual capacities are available from site specific static load testing failure.

3 It is accepted that 5D is a conservative guide and, in many cases, a minimum depth of 3D will prevent punching. It is recommended that specific ground condition analysis is carried out if founding layer depths are less than 5D, or piles are in closely spaced groups.

6.3 Tension capacity

Tension capacity factors are similar to those discussed for compression loads but have an additional element – a "conical" or "cone" pull-out capacity.

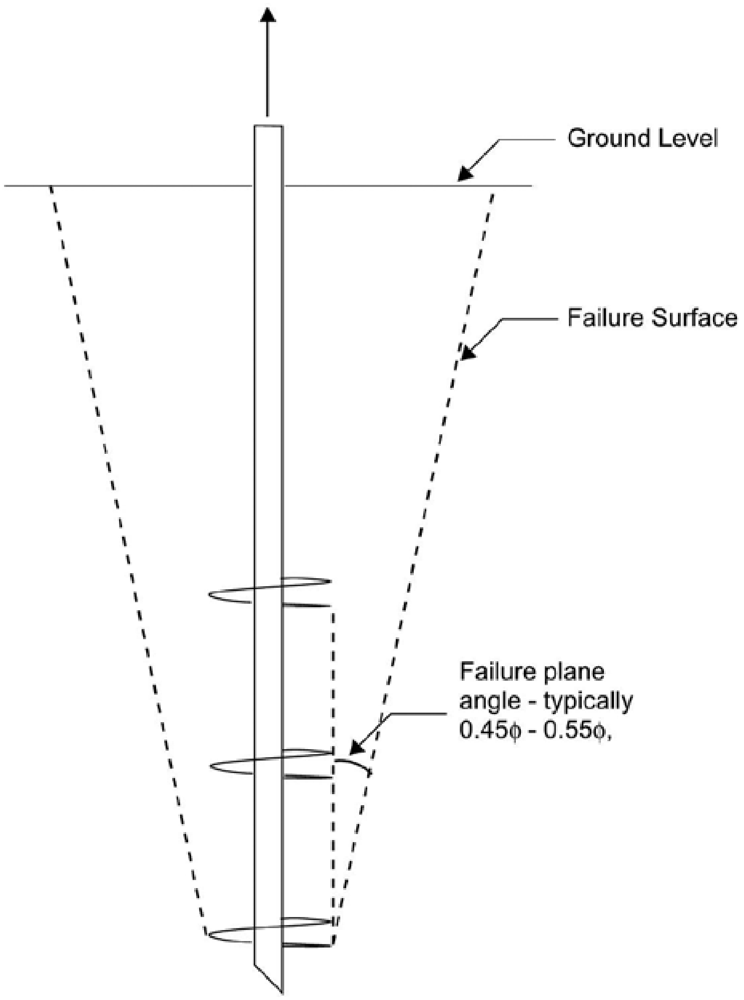
Cone pull-out failure occurs when shear forces are reduced to zero along the 'failure plane'. At this critical point the pile and some surrounding soil is pulled out in the shape of a truncated inverted cone or pyramid (see Figure 6.3). The angle of pull-out will vary depending on soil type and is typically between 0.45 to 0.55 times the soil angle of friction, ϕ.

Total tension or "Uplift" capacity should be the smallest of:

- The sum of the helix bearing capacities (if widely spaced helices) plus shaft friction capacity; or
- The sum of the upper helix capacity plus helix cylinder friction capacity (if closely spaced helices) plus shaft friction capacity, or
- The cone pull out capacity.

Where tension capacity is critical to the design and given the more potentially catastrophic mode of failure, a lower strength reduction factor is recommended.

Figure 6.3: Cone Pull Out



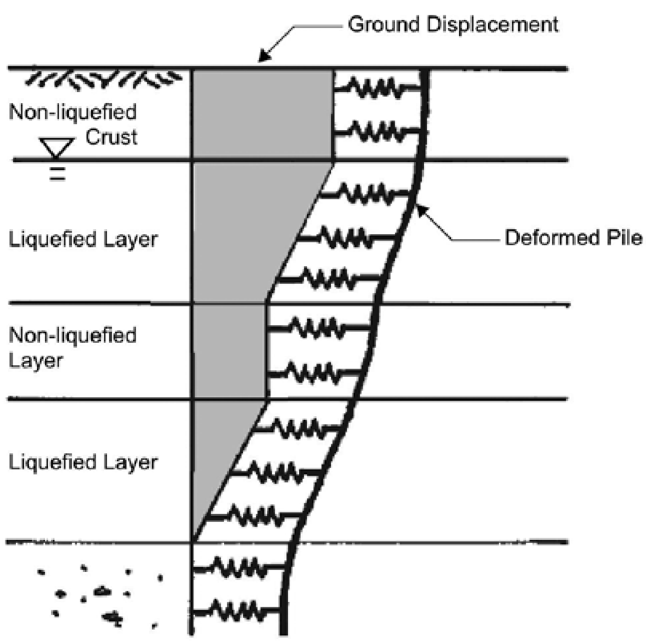
6.4 Lateral capacity

Lateral capacity-related failure mechanisms are overturning failures and translational/sliding failures. Analyses such as *Brom's methods* [9] or software such as LPILE or GROUP can be used where design for lateral loading is critical. Some recommendations to minimize the likelihood of lateral capacity failures are provided in *New Zealand Building Code, Structure Foundations, Verification Method* (B1/VM4) [10].

The lateral capacity of a screw pile will depend on the:

- Soil strength
  - In liquefiable soils, residual soil strengths should be designed for in accordance with [4]. Further guidance on designing for shallow and deep pile foundations in liquefied soils can be found in [5]
  - Where a non-liquefied crust sits above a liquefied soil large lateral passive soil pressures can occur resulting in pile shaft deformation (see Figure 6.4)
- Amount of soil disturbance during installation
  - During installation the ground over the upper part of the shaft, generally to a depth of 4D, can be disturbed and loosened. A reduction in lateral resistance over the upper 4D of any screw pile installation should be applied during the design phase (the use of a "true helix" is recommended as this will minimize soil disturbances and increase lateral resistance).
- Degree of pile head fixity
  - rotation of the pile head will be greater in weaker soils leading to a reduction in lateral capacity
- Diameter, length and strength of the shaft.
  - concrete infilling and reinforcement of the pile shaft (where the ground allows) can improve lateral capacity.

Figure 6.4: Effect of Liquefaction and Lateral Spreading [5]



6.5 Installation torque and capacity

The torsional resistance generated during screw pile installation is an indication of soil shear strength and provides an alternative (empirical) way to find the capacity of a screw pile.

A relationship derived between ultimate geotechnical capacity and installation torque is shown in Table 6.3.

Table 6.3: Capacity Based on Torque

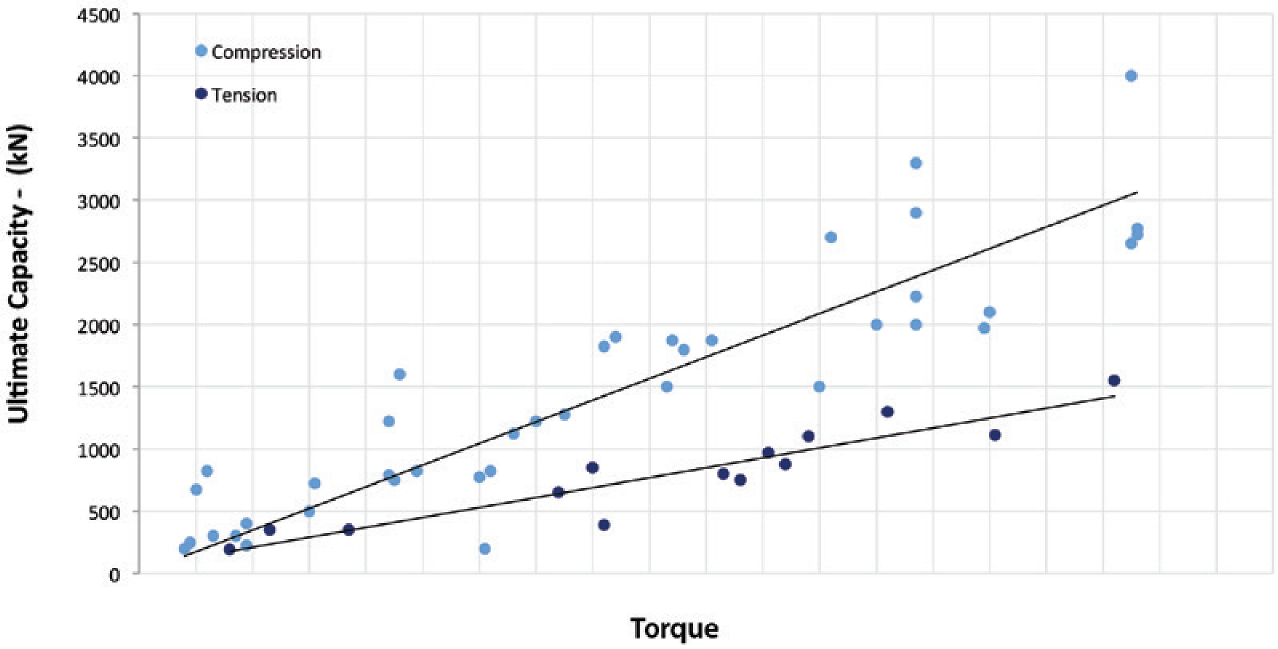
Ultimate Geotechnical Capacity Q_u = KT *
• Q_u = Ultimate geotechnical capacity • K = Capacity to torque ratio (This is not a consistent number and will vary with soil conditions, size of pile, helix configuration and installation) • T = Installation torque.

** This correlation is only valid where the soils below the helix are equal to or stronger than the soil in which the torque is measured. Negative skin friction may be a factor in the derived capacity.*

By recording large volumes of installation torque data in various soil conditions and for differing screw pile size and helix configurations, screw pile companies are able to design and provide screw piles of a certain capacity based on the above relationship.

Figure 6.5 shows how empirical torque data can be used to estimate (ultimate) screw pile capacity in both compression and tension loading in a certain soil condition. Best-fit lines are drawn from which capacity values can be read.

Figure 6.5: Example Graph of Ultimate Capacity versus Installation Torque



Confidence in providing capacity figures comes from installation experience, specific load testing and the use of monitoring systems. For torque measurements to be relied upon there needs to be:

- Calibration of the force inducer
- Consistent use of equipment
- Competence in pile installation (verticality and rate of installation)
- Consistent soil conditions
- Measurements taken over the last metre of installation or 3D (whichever is the greater)

Whilst this method of determining screw pile capacity is a good indicator of capacity, it is essential that conventional geotechnical investigations and theoretical design is used to confirm:

- the target founding depth
- soil strength below the founding layer is of adequate strength
- the overall capacity
- on-site installation torque.

Key Point

Generic torque to capacity relationships provided by the installer must be validated through site specific investigations and load testing.

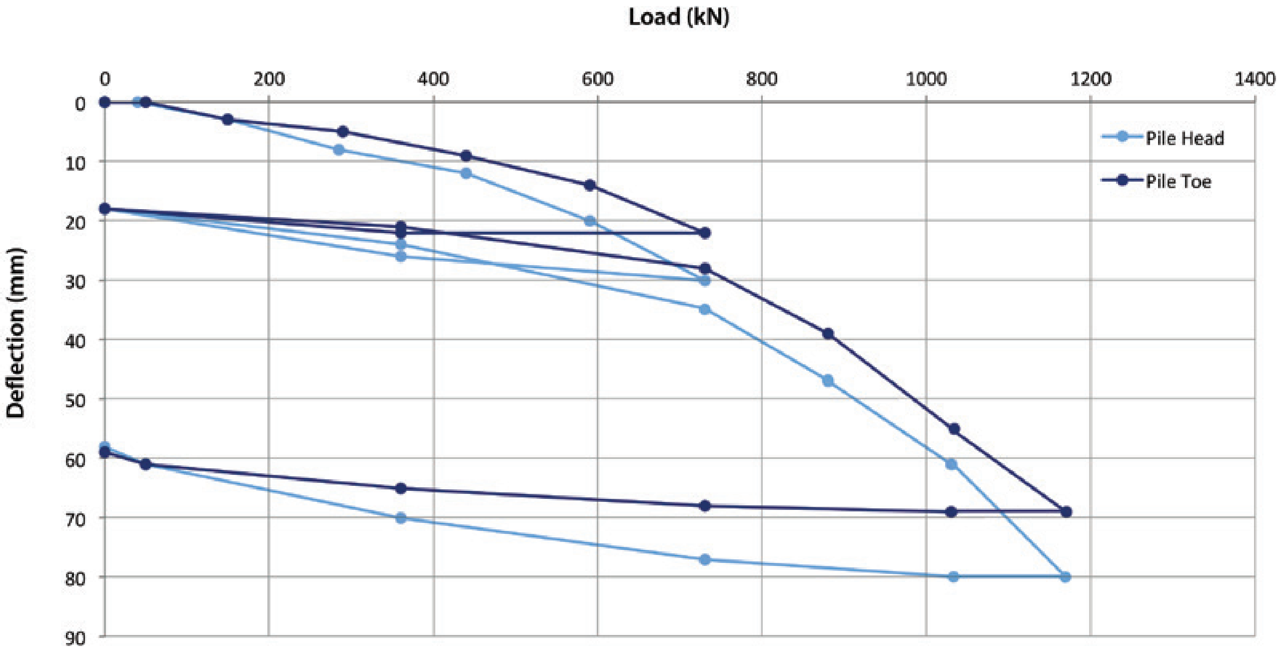
6.6 Vertical deflection

Vertical movement (deflection) of screw piles will occur in all cases on loading and may be greater than that of conventional comparable bored or driven piles. The vertical deflection, or 'settlement', of screw piles on loading arises from:

- helix plate deflection[4]
- soil movement and
- elastic shortening of the shaft

An example of load versus deflection showing relative pile head and toe movement is shown in Figure 6.6. A pile is initially loaded up to 750kN then unloaded, loaded up to nearly 1200kN and then again unloaded.

Figure 6.6: Example of Load versus Deflection



The pile installation company may have test data available for similar piles in similar soil profiles that can be used for comparison. However, as even small variations in ground conditions can affect load/deflection, where the structure is sensitive to vertical deflections, it is essential that site-specific full load testing is carried out.

Key Point

Where pile deflection is a critical design element it is recommended that site specific load testing must be undertaken.

4 As the screw piles become loaded the helix plate will naturally bend or 'deflect' upwards at its outer edge. This deflection of the helix plate is the mechanism that enables the screw pile to develop its full capacity.

6.7 Pile spacing and group effects

The design will need to reflect whether the pile foundations are acting as a single pile or as a pile group. This is particularly relevant when piles are spaced closer than about 3-4D or when there is a compressible layer underlying the founding or bearing layer or when considering cone pull-out.

A slight pile inclination may be one way of achieving increased spacing and maintaining the estimated vertical compression capacity.

Due to the typically small shaft diameter compared to the helix, reductions in lateral capacity due to group effects are much less likely than for other pile types.

6.8 Strength reduction factors

[10] provides recommendations on strength reduction factors for deep foundations. Some organisations also have their own requirements around strength reduction factors such as the *New Zealand Transport Agency Bridge Manual* [11] and *Transpower Line Foundation Strategy* [12].

[1] provides a risk-based assessment process that takes into account:

- ground conditions
- the amount of geotechnical data
- experience in the ground conditions
- method of derivation of load capacity
- monitoring during construction
- specific testing undertaken, such as static load testing.

Section 8.2 of [1] recommends testing shall be performed to verify pile serviceability where the basic strength reduction factor is greater than 0.4 and the average risk rating is greater than 2.5. However, current practice in New Zealand accepts basic strength reduction factors of 0.45 to 0.55 without specific load testing.

7. Screw Pile Structural Design

7.1 General structural design requirements

Structural designers need to take into account the following factors when designing for the structure and its foundations:

- The importance level of the structure (clause A3 of the New Zealand Building Code) – this will determine the magnitude of earthquake and wind loadings required for the structure and foundations as defined in [3]
- The design life of the structure – for permanent applications the Building Code requires a minimum life of 50 years. For more critical structures a minimum life of 100 years may be required. Screw piles can also be used for temporary anchoring applications or for temporary structures
- Serviceability versus Ultimate Limit State – the pile design should ensure:
  - avoidance of adverse settlement or damage in the serviceability limit state
  - reliable behaviour in the ultimate limit state
- The difficulty in inspecting and repairing the foundations – the designer may recommend an elevated damage limit state (analogous to SLS 2)
- The performance of structural components in the event of unforeseen overload, adverse conditions, and accidental damage during installation
- Outcomes if a pile, or piles, exceed the agreed vertical or horizontal positional tolerances.

Appendix B provides a checklist of items that need to be considered during the design and installation phases.

7.2 Assessment of loadings

The component parts of the screw pile and any associated connections must be strong enough to transfer the load from the structure to the ground during installation and when in service.

7.2.1 Loadings during installation

The torque forces set up during installation – an assessment of the peak torque required to install the pile will need to be made.

7.2.2 In-service Loads

Loading effects over the design life of the pile must comply with [3], or project specific requirements, such as [11] and [12].

Loadings specific to screw piles include any flexural or lateral loads and arise from:

- accidental pile/column eccentricity
- seismic soil/foundation interaction
- slope instability
- self-weight loads.

7.3 Screw pile components

The structural design of the piles (shaft, helix, and connections) should be carried out in accordance with the following standards:

- *AS 2159 Piling Design and Installation* [1]
- *AS 1163 Structural Steel Hollow Sections* [13]
- *AS 1554 Welding of Steel Structures* [14]
- *AS/NZS 3678 Structural Steel* [15]
- *AS/NZS 4671 Steel Reinforcing Materials* [16]
- *NZS 3404 Steel Structures* [17]
- *NZS 3101 Concret Structures [18].*

7.3.1 Shaft

The dimensions of the shaft are based on the net thickness after making allowance for corrosion. The shaft design should also take into account whether concrete in-filling or reinforcement is required.

7.3.2 Helix

A true helix has a constant pitch angle, a plate that is perpendicular to the shaft, and the internal edge parallel to the shaft. True helix form is important for weld penetration and structural integrity.

A "true helix" form will assist in the:

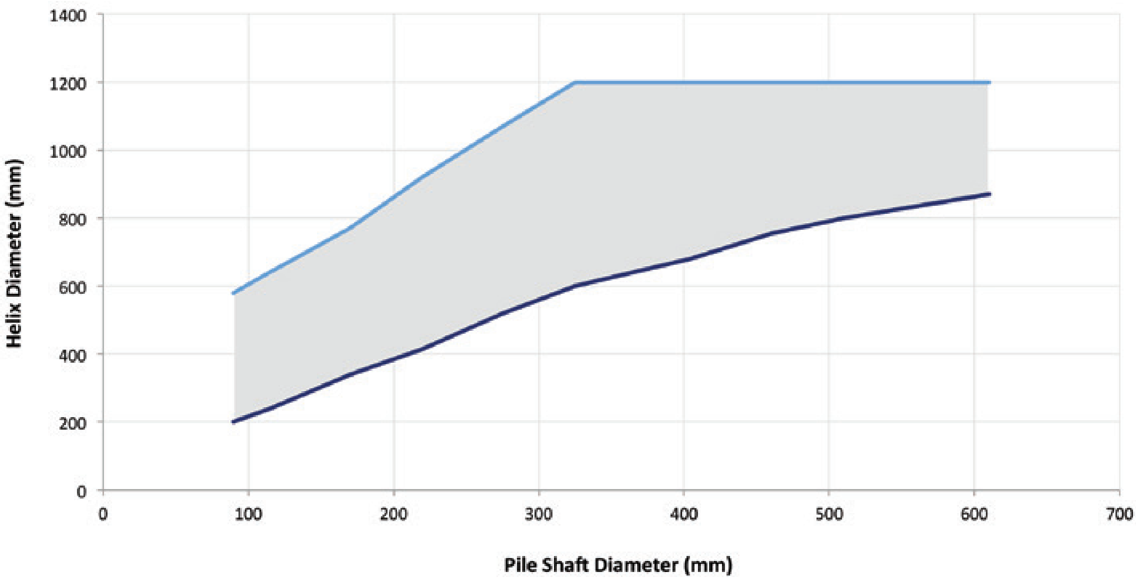
- minimisation of ground disturbance
- maximisation of penetration
- mitigation of risk of spinning without advancing
- reduction of settlement on loading.

As with the shaft, the dimensions of the helix plate should be based on the net thickness after making allowance for corrosion.

Figure 7.1 shows typical examples of helix size relative to shaft size.

The design of the helix must follow a rational and proven analysis method validated through 'tests to destruction' for representative pre-qualified configurations, *PJ Yttrup and Abramsson: "Ultimate Strength of Screw Piles in Sand"* [19].

Figure 7.1: Typical Helix to Pile Shaft Size



7.3.3 Connections and splices

Connections to the foundation system must comply with [18]. Design connections need to account for the transfer of potentially high bearing pressures from the pile and also any actions arising due to expected or adverse scenarios. A mechanical connection is recommended to ensure direct load transfer between the pile and structure, especially where tension and/or flexure may be present. If an indirect load transfer mechanism is being considered, such as using concrete infill with or without reinforcing, and concrete to steel bond is involved in the load path, the designer must have confidence in the concrete placement and compaction. The designer will also have to verify the load transfer can be reliably achieved without slippage. The connection design also needs to consider all durability issues.

Where splices are needed to meet pile length requirements these should be designed to transfer all design actions without slippage or distortion.

Key Point

The screw pile and any connections must be of adequate strength to transfer the load from the structure to the ground during both installation and when in service.

7.4 Modes of failure summary

Typical modes of geotechnical and structural failure for screw piles and mitigations are summarised in Table 7.1.

Table 7.1: Modes of Failure Summary

Mode of Failure	Mitigation
Geotechnical	
Friction • Tension/pull-out • Compression *Bearing* • Punching due to soft soil layer underlying founding material *Deflection* • Excessive deflection to develop load capacity *Installation* • Presence of objects or hard layers prevent installation • Pile spins/rotates on hard layer • Ground disturbance on installation	• Adequate geotechnical investigation, both depth and coverage (Section 5) • Confirm that ground conditions are appropriate for screw piles (Section 3) • Lower strength reduction factor for tension/uplift loads (Section 6) • Limit theoretical estimates of geotechnical capacity where ground conditions are unknown/variable (Section 6) • Undertake site specific load test(s) to confirm installation and validate capacity and deflection (Section 10) • Validate "generic torque/capacity" with site specific data (Section 6) • Understand structure performance requirements and limit geotechnical capacities such that deflection requirements for structure can be met (Section 6) • Use of a "true-helix form" (Section 7).
Structural	
Helix • Excessive deformation/bending • Buckling failure *Connection Helix to Shaft* • Weld failure • Fatigue failure *Shaft* • Buckling failure • Torsional failure • Weld failure – seam weld • Fatigue failure • Connection failure *Load transfer pile to structure* • Pull out of pile from foundation *Excessive Corrosion* • Premature structural failure *Installation* • Structural failure • Position out of tolerance.	All design and installation loadings fully understood (Section 7) Limit installation torque to avoid pile failure (Sections 7 and 8) Weld integrity testing (Section 8). Undertake site specific load test to validate pile performance (Section 10) Use appropriate mechanical connection to slab, as well as pile to pile connection (Section 7) Environmental conditions tested and confirmed (ie pH) (Sections 5 and 8) Quality control and manufacturer testing process (Section 8) Use of verified helix design software.

8. Materials, Durability and Manufacturing

8.1 Durability

Design for durability from the base of the pile through to its connections at or above the ground surface should take into account environmental conditions, such as the corrosive nature of the soil and groundwater.

It is recommended that corrosion allowances for screw pile design are based on [1] Section 6.5 *Design for Durability of Steel*, and Table C5.3.2.1 [17]. Steel treatments such as galvanising, hot zinc coating, and polymer or epoxy coatings designed to improve durability have not yet been proven for screw piles.

8.2 Materials

Materials used for the manufacture of screw piles should satisfy the following standards:

- **Shaft** – [13] *or API 5L Specification for Line Pipe Standards* [20], minimum Grade 350 MPa [20] is strongly recommended to ensure seam weld integrity
- **Helices** – Minimum Grade 350 plate onto AS/*NZS 1365 Tolerences for flat-rolled steel products* [21]
- **Concrete** – Infill should be a minimum 30 MPa produced in accordance with *NZS 3104 Specification for Concrete Production* [22].

See Appendix D: Screw Pile Shaft Specification and Design, D2.

8.3 Manufacture

For the screw pile shaft, the two critical manufacturing factors are:

- The quality of shaft manufacture
- The integrity of the seam weld.

Screw piles are typically manufactured off site and transported ready for installation. Where piles need to be spliced to increase the overall pile length, this is typically done by means of a full strength butt weld in situ or with specifically designed welded couplings.

Base materials, fabrication tolerances, welds and weld procedures, and quality controls of the manufacturers' testing processes are all critical to the installation, performance and structural reliability of screw piles. Further information and recommendations are provided in the following sections for each element.

8.3.1 Shaft

The following factors must be considered in the design and specification of the base shaft:

- Torsional capacity – torsion results in a circumferential shear in the central shaft, and may be calculated from the circumferential steel yield value
- Integrity of weld seams
- Longitudinal capacity (long-term load capacity).

For further information on screw pile shaft design see Appendix D.3.

8.3.2 Helix

Helices should be manufactured using suitable equipment to ensure a "true helix" is formed. Only when the internal edge is parallel to the shaft will weld root penetration and throat thickness of the weld will be homogeneous.

Correct helix form requires:

- The pitch at the inside and outside of the helix to be equal (+/- 4% of the helix flange width)
- Constant gradient of the spiral
- Any radial measurement across the helix to be perpendicular to the shaft (+/-4% of the helix flange width (outstand))
- Second and third helices to be positioned on the shaft at an exact multiple of the pitch
- The lead edge may need to be designed to displace obstacles.

The shaft connection should be manufactured in accordance with [14] (plus a minimum level of NDT that is not less than 10%) performed by *AS/NZS 2980 Qualification of Welders for Fusion Welding of Steels* [23] certified welder. The weld material should be 480MPa-grade suitable for seismic conditions.

The helix should be fully welded all round, both above and below the helix plate, and the lead and trail edge should be sealed in order to prevent crevice corrosion.

An example technical specification for a helix can be found in Appendix C: Screw Pile Technical Specification.

Key point

The torsional capacity and integrity of weld seams are key factors during installation (particularly to withstand the very high torsional demand imposed while the pile is being screwed in to the ground).

9. Construction Practice

9.1 Installation

Equipment used for installation needs to deliver sufficient torque to the pile without damaging it. The installation torque must not exceed the maximum pile capacity with a suitable safety factor and safety cut-off in the equipment used for installation. Figure 9.1 below shows the equipment and set-up needed for installation of a screw pile structure.

Figure 9.1: Typical Installation Set-up for a Screw Pile

The following points are recommended good practice for screw pile installation:

- Location of critical services (water, internet, gas etc) should be determined prior to installation
- When the screw pile is installed with a specialized machine it must be operated by a certified installer trained in the use of that particular machine
- Calibration of installation equipment and torque measuring devices should be carried out at least every 6 months
- Where feasible, the same power-head should be used throughout a project, so that the measured torque can be compared between piles. The pile should be installed in a continuous manner at a constant rate using variable speeds.
- Rotation and advancement of the pile should be measured and recorded
- Installation is complete when the required tip embedment depth and the minimum required torsional resistance have been met.

The following should be monitored during construction and installation:

- Positional tolerance of the pile head
- Inclination and alignment of the pile
- Torsional resistance during the entire installation of the pile to be correlated with geotechnical investigations
- Quality assurance of any site welding to splices (additional NDT)
- Rebar (reinforcing steel bar) check
- Volume check of Tremie grouting (Tremie: a method for placing high quality concrete under water).

9.2 Pile construction record card

It is standard practice for any piling project to complete Pile Construction Record cards for screw piles.

They should contain the following:

- Contract, structure and name
- Pile number, location, pile type and pile dimensions, installation date
- Details of any predrilling or other preparatory works
- Ultimate limit state (ULS) load requirement
- Profile of installation torque or pressure with depth and design torque if provided
- Powerhead and excavator used
- Expected and actual founding levels
- Pile head position in relation to design
- Inclination
- Concrete/grouting records
- Design and actual constructed elevation of the top of the pile
- Piling contractor's signature verifying that all the work has been completed satisfactorily.

An example of a screw pile construction card is provided in Appendix E.

10. Testing Requirements and Practices

10.1 Purpose of testing

While load testing of piles is not mandatory it is strongly recommended. There are a number of advantages in undertaking load tests particularly for foundation systems such as screw piles. These advantages include:

- When designers or installers do not have experience in similar ground conditions pile deflection and torque-to-capacity characteristics of the pile in that specific site can be accurately determined
- The likelihood of construction delays due to design load requirements not being met will be reduced
- Strength reduction factors can be increased and consequently, the number of piles can be reduced – the percentage of piles tested directly correlates to the final design strength reduction factor
- Load vs Settlement and Installation Torque vs Load performance values can be directly measured
- Greater clarity in construction direction can be achieved, especially when installing in marginal soil conditions
- Load tests to destruction for helix and geotechnical performance can be verified
- Levels of correlation with CPT and /or boreholes at test locations can be determined leading to higher confidence levels in interpolating conditions at other parts of the site.

Figure 10.1 below shows a static load set-up.

Figure 10.1: Static Load Test Set-up

10.2 General testing requirements

Guidance on testing requirements can be found in [1].

Sacrificial pre-production load testing should be undertaken in accordance with [1] Appendix A: Static Load Test. This standard provides recommendations on reaction systems, equipment, and measurement of displacement, loading schedules, recording and reporting. Each test should be adapted as required to suit the site, project requirement and purpose of the test.

Testing should follow the procedures outlined in [1]: Table A1 Loading Program – Compression Test Procedure and Table A2 Loading Programme – Lateral or Tension Test Procedure. The acceptance criteria for tension and load tests should be carried out in accordance with [1] Section 8.4.3.

Variations to AS 2159

Some piling contractors may request variations to the testing proposed in [1] including:

- Amending the pile settlement criteria to 10% of the pile diameter (where piles are greater than 500 mm diameter) to determine ultimate geotechnical strength rather than that detailed in [1] Table 8.4.3.1 – provided this meets the structure design criteria
- Extending the Serviceability Limit State (SLS) load to monitor long-term creep
- Cyclic testing including tension and compression testing
- Specific loading requirements as determined by the project.

10.3 Other considerations

- The testing arrangement should avoid interaction between reaction points and the test pile
- Pile shafts need to be adequately designed to take higher test loads. Where the design uses concrete infill, piles may need to be in-filled prior to testing
- Test piles are installed preferably using the plant and equipment proposed for production installation. Site specific measurements can be used and compared as part of construction monitoring
- Pile deflection measurements taken at the head and the toe to determine elastic pile shortening
- Test piles should be located near previous geotechnical investigation boreholes or CPTs
- Load test should include any predicted additional loads such as NSF from liquefaction.

Key point

Project specific load testing of piles is not mandatory, however it is highly recommended.

11. Producer Statements

11.1 Producer statements – pile designer

IPENZ Practice Note: Guidelines on Producer Statements [24] provides background and recommendations on the use of Producer Statements.

With respect to screw pile foundations, a Chartered Professional Engineer who is competent in screw pile design will need to sign each Producer Statement.

There are currently three Producer Statements issued by Chartered Professional Engineers. These have been jointly developed by the Institution of Professional Engineers (IPENZ), the Institute of Architects (NZIA) and the Association of Consulting Engineers (ACENZ) and are available via their websites.

For the screw pile design the pile designer (Chartered Professional Engineer) will provide a:

- **PS1 Design** –the pile designer is responsible for the design of the screw pile foundation system in its entirety. This includes the geotechnical capacity of soils, structural capacity and durability of each element and also includes all connections between the pile stem and the ground beam or foundation. The pile designer will nominate the appropriate level of construction monitoring required on the PS1. The pile designer is also responsible for coordinating with the engineer responsible for the structure to agree all loadings, assumptions and pile/foundation interfaces.
- **PS2 Design Review** – if requested by the local BCA or client's agent
- **PS4 Construction Review** – it should be the pile designer's responsibility to undertake construction monitoring in order to verify the installation and construction meets the approved design, contract drawings and specifications.

11.2 Producer statements – pile contractor

Schedule 6 of *NZS 3910 Conditions of Contract for Building and Civil Engineering Construction* [25] contains a "Form of Producer Statement – Construction (PS-C)" Contractors are required to complete this form for the part of the installation or component for which they are responsible.

The pile contractor should be responsible for preparing a PS-C.

12. Procurement

In New Zealand screw piles are typically considered a specialist foundation product and, as such, are usually procured under a Design and Construct contract with a manufacturer who is experienced in screw piles.

An experienced Contractor will have:

- Experience with screw piles over a variety of projects and site conditions
- The knowledge to provide effective and efficient designs from specific test databases held by contractors
- The ability to mobilise and commence construction quickly
- A good understanding of the suitability of a particular screw pile for a project
- Specific knowledge of the design of the shaft, helix, helix pile toe, helix lead edge design and special high penetration heads
- Large stock holdings.

Bibliography

[1] *AS 2159 Piling Design and Installation*, 2009.

[2] *NZGS Guideline for Field Description of Soil and Rock for Engineering Purposes*, 2005.
www.nzgs.org/publications/guidelines/soil_and_rock.pdf

[3] *AS/NZS 1170 Structural Design Actions*. (Parts 0,1,2,3,5) 2002– 2013

[4] *NZGS Guideline "Geotechnical Earthquake Engineering Practice – Module 1 – Guideline for the identification, assessment and mitigation of liquefaction hazards"*, 2010.
www.nzgs.org/Publications/Guidelines/GeoEarthquakeEngineer.pdf

[5] *MBIE Guidance "Repairing and Rebuilding houses affected by the Canterbury Earthquakes"* version 3, 2012 (with regular updates and supplementary guidance).
www.mbie.govt.nz

[6] *HelixPile software*, 2012.
www.menglim498.files.wordpress.com/2013/04/pile-design-and-construction.pdf

[7] *D. J. Clayton, "Basic Helical Screw Pile Design,"* (2005).
www.geotecheng.com/papers/guidelines/guidelines_helical_pile.pdf

[8] *W. J. Tomlinson M.J. Woodward, Pile design and Construction 5th Edition* (2007).

[9] *Brom, "Brom's method for analysis the lateral capacity of single piles,".*
www.engineering.com/Search?q=brom

[10] *New Zealand Building Code, "Verification method B1/VM4 Foundations,"* (2014).
www.building.govt.nz/UserFiles/File/Publications/Building/Compliance-documents/B1-structure-1st-edition-amendment-12-rp.pdf

[11] *New Zealand Transport Agency, "Bridge Manual,"* (2014).
www.nzta.govt.nz/resources/bridge-manual/bridge-manual.html

[12] *Transpower, "Transpower Draft Foundation Design Guide for Transmission Lines*". June 2013 (log in permission required from Transpower to view this article).
www.transpower.co.nz

[13] *AS/NZS 1163 Cold-formed Structural Steel Hollow Sections* (2009).

[14] *AS/NZS 1554 Welding of Steel Structures* (2014).

[15] *AS/NZS 3678 Structural Steel* – Hot-rolled plates, floorplates and slabs (2011).

[16] *AS/NZS 4671 Steel Reinforcing Materials* (2003).

[17] *NZS 3404 Steel Structures*, (2009).

[18] *NZS 3101 Concrete Structures*, (2006).

[19] *PJ Yttrup and Abramsson: "Ultimate Strength of Screw Piles in Sand", Australians Geomechanics Society Vol 38, No 1, March 2003* (available online to AGS members).

[20] *(American Petroleum Institute) API 5L Specification for Line Pipe Standards* (2012).

[21] *AS/NZS 1365 Tolerances for flat-rolled steel products* (1996).

[22] *NZS 3104 Specification for Concrete Production* (2003).

[23] *AS/NZS 2980 Qualification of Welders for Fusion Welding of Steels.* (2007)

[24] *IPENZ Practice Note: Guidelines on Producer Statements* (2014).
www.ipenz.nz/home/news-and-publications/news-article/practice-note-guidelines-on-producer-statements-2014

[25] *NZS 3910 Conditions of Contract for Building and Civil Engineering Construction* (2013).

Appendix A
Considerations for Geotechnical Investigations for Screw Piles

Table-Geotechnical Investigations for Screw Piles

Test Item	Developing overall soil, rock and groundwater profile	Prove Founding Material	Estimation of deformation and settlement	Identification of slip plane	Ground conditions such as environ-mental and contamination
Hand Auger Bores – Typically a 50 mm diameter manually bored hole to 3-5 m depth. In situ testing may include shear vane, or Scala penetrometer testing.	Since the ground beneath the helix needs to be proved, hand augers are unlikely to be appropriate except for shallow piles.	Limited to a depth of about 3-5 m and cannot penetrate stiff or dense material or rock or progress through very soft soils.	No, not adequate depth.	No, disturbed soil samples only.	For shallow depths however careful cleaning of equipment is required to avoid cross contamination.
Test Pits – Test pits/ trenches provide access for taking samples, carrying out in situ tests and to permit the in situ condition of the ground to be examined in detail both laterally and vertically. Also provide a means of determining the orientation of discontinuities of the ground.	Unlikely to be appropriate for screw pile design except for investigating potential shallow obstructions and obtaining samples for laboratory testing.	Depth limited 3-5 m.	No, not adequate depth.	Yes, if shallow within 3-5 m depth.	Good for collection of samples with minimal risk of cross contamination where undertaken carefully.
Cone Penetrometer Tests (CPT) – *In-situ* testing method used to determine geotechnical engineering properties of soils and delineate soil stratigraphy. Test method consists of pushing an instrumented cone tip first into the ground at a controlled rate and recording the resistance. The total cone resistance is made up of side friction on the cone shaft perimeter and tip pressure. Pore pressure and shear wave velocity data may also be obtained depending on the equipment configuration. This test is generally not well suited to very weak soils unless a specific high resolution cone is used or dense gravel deposits and hard soil or rock due to the high likelihood of refusal.	Particularly useful in identifying thinner layers of hard or very weak soils that could influence capacity or installation. No retrieval of soil samples hence soil characteristics are inferred from readings. CPT's are also relatively low cost but it is recommended that some machine boreholes be drilled to assist in interpretation of the CPT's particularly since no soil is retrieved during pile installation.	Able to push 30 m plus, however cannot be pushed into rock or extremely hard soils or dense gravels and hence in some situations may not be able to prove founding layer. Where soil strength is highly variable (e.g. alluvial) a CPT test is a relatively cheap way of testing at each pile location.	Yes, particularly for "sandy" deposits.	No	No

Test Item	Developing profile	Prove Founding Material	Estimation of deformation and settlement	Identification of slip plane	Ground conditions
Machine Boreholes – Drill rig progresses drilling into the soil or rock and retrieval of samples for logging and laboratory testing. Forms of progressing the drilling include wash, auger, rotary, triple tube, cable tool, open barrel, percussion and sonic. Selection of the method is typically based on a combination of equipment availability and soil or rock type expected at the site. In situ testing such as Standard Penetrometer Testing (SPT) and down hole shear vane testing can be undertaken. Instrumentation for recording groundwater levels, deformation, settlement, slip movement can be installed within the borehole.	Since no soil is excavated during screw pile installation, machine borehole drilling is an opportunity to visually assess the soils. Can be drilled to any depth hence appropriate for shallow and deep screw piles. Can be done in combination with CPT tests which are usually quicker and lower cost.	The recommended method for proving founding layers as boreholes can penetrate through most soil and rock types.	Yes. Undisturbed samples can be obtained for site specific laboratory testing.	Yes	Yes, with careful cleaning to avoid cross contamination.
Laboratory Testing – Testing for geotechnical properties and strength, environmental such as pH for durability assessments and/or contamination can be undertaken on samples retrieved for the site investigations. All testing should be undertaken at an International Accreditation New Zealand (IANZ) accredited laboratory.	N/A	Strength testing (uniaxial compressive strength [UCS], triaxial, direct shear).	Consolidation testing.	N/A	Specific laboratory testing for contaminants and pH undertaken on soil and water samples specifically collected for that purpose.
Instrumentation – Consideration should be given to whether any instrumentation should be installed within the borehole for the measurement of groundwater levels and slip movement. This may include piezometers or inclinometers.	Piezometer allows for on-going monitoring and sampling groundwater.	N/A		Inclinometer gives confirmation slip plane location and on-going monitoring allows measurement rate of movement.	On-going sampling water possible piezometers.
Sustained static load testing – Able to carry out load tests quickly and efficiently and they can be installed and removed on completion of testing.	Recommend where ground conditions are different or variable or unsure of suitability.	Provides indication of influence of weaker layer beneath founding layer if deflections high.	Recommended where there is any doubt over the performance of the screw pile and its suitability for the proposed site or structure.	N/A	N/A

Appendix B
Pre-Design, Design and Installation Checklist

	Client	Client's Designer	Screw Pile Designer
Pre Design			
Has adequate geotechnical site investigations been carried out to prove the depth, strength and thickness of founding layers, and other load s such a landslide and liquefaction?			
Have Screw Piles been evaluated for suitability with respect to both geotechnical conditions and structural requirements?			
Has the method of obtaining screw pile design been agreed with the Client (i.e. Clients consultant to design or Design and Construct contract)?			
Have the Client's requirements, design load cases, site constraints been adequately determined and advised?			
Is the following shown on the Drawings and/or Specification? • Design Life • Loads • SLS and ULS Deflection Criteria • Requirement for stem to be concrete infilled • Requirement for load testing • Any other particular project design requirements.			
Design			
Has the Screw Pile Designer agreed adequate geotechnical site investigations have been carried out to prove the depth strength and thickness of founding layers, and other loads such as landslide and liquefaction? If not, Screw Pile Designer should advise and undertake as considered necessary.			
Does the SPD have all the required design requirements?			
Has the SPD evaluated and allowed for all geotechnical requirements? • All potential failure mechanisms including bearing, punching, pull out, lateral loads and capacities • Adequacy of founding layer and risk of punching • Seismic effects such as liquefaction, negative down drag, and lateral loading • Settlements • Capacity based on analytical assessment or historical performance from other sites. Where historical performance is screw pile size and ground conditions consistent.			
Design			

	Client	Client's Designer	Screw Pile Designer
• Has the SPD evaluated and allowed for all design and construction loadings? Structure will cope with predicted settlements • All installation torque and construction loads • Buckling due to lateral loading from seismic or other loads • Corrosion resistance meet the required Codes • Load transfer at foundation • Confirmed "True Helix" form.			
Design strength reduction factor and degree of load testing agreed.			
Has a PS1 (and PS2) been completed by Chartered Professional Engineer and approved by the Local Authority?			
Professional indemnity insurance limit and cover agreed.			
Installation			
Have materials been supplied to the agreed standard?			
Can the installer demonstrate how capacity will be validated?			
Is the installer fully trained in the installation of screw piles.			
Has the installer ensured and put in place measures so that the pile shaft will not be overstressed?			
Contingency plan if pile cannot be installed to agreed depth or does not obtain the agreed capacity.			
Has the installer provided Inspection & Test Plan and Construction Work Plan following the approved QA procedures?			
If test pile undertaken does it prove compliance with design requirements. If not, have changes been made and approved?			
Has the installer confirmed the pile set out locations?			
Has the supplier and installer provided appropriate manufacturing QA which may include: • "True Helix" form • Preapproved welding procedures • Welder competency test certificates • Mill and testing certificates for shaft and helix steel.			
Has the installer provided Pile Construction Record Cards, test and as built records?			
Has construction monitoring been carried out by a Chartered Professional Engineer to the level indicated in the PS1/PS2 and a PS4 been completed?			

Appendix C
Technical Specification for the Design, Construction, Installation and Certification of Screw Piles

SP - SCREW PILES

SP0.0 INDEX

SP1.0 Preliminary

Refer to the Conditions of Contract and Preliminary and General, which shall apply to this section of the Contract Works.

This specification applies to the design, construction, installation and certification of the screw piles for the contract.

SP2.0 Roles and responsibilities

The roles and responsibilities pertinent to this Screw Pile specification are summarised below:

The "Engineer" (Client's Advisor)

The Engineer shall be responsible for providing sufficient information to the Pile Designer to allow the design of the screw pile. As a minimum, the information shall include the following:

a) Design life, structure importance level and specific durability requirements
b) Compression, tension and lateral structural loads at each individual pile location including static, seismic SLS and seismic ULS load cases, requirement for concrete infilling of the shaft

c) The maximum permissible deflection at serviceability and ultimate limit states

d) Identify any ground effects that may impart additional load on the screw pile foundations. This may include alterations in groundwater, ground settlement or seismic hazards. The resulting additional load or loss in strength/stiffness of the soil shall be detailed within the Construction Drawings

e) The pile design performance criteria including tolerances

f) Specific material and test requirements such as compliance with AS1163 or API 5L

g) Any particular requirements for pre-construction and production load testing including acceptance criteria.

The Engineer shall be responsible for undertaking the following:

a) Review of the Piling Contractor's methodology for executing the pre-production load testing as appropriate

b) Review of the Piling Contractor's methodology for executing the installation of the screw piles

c) Monitor as appropriate installation of the screw piles and load testing, the frequency for which shall be at the discretion of the Engineer.

The "Piling Contractor"

The Piling Contractor shall be responsible for constructing and installing the screw piles in accordance with the Construction Drawings and Specification. The Piling Contractor shall be responsible for preparing a Producer Statement – Construction (PSC), and obtain written acceptance of the PSC by the local authority.

The Piling Contractor shall commission the Pile Designer.

The "Pile Designer"

The Pile Designer shall be responsible for the design of the screw pile system, including but not limited to assessing the:

- geotechnical capacity of the soils
- structural capacity of each element of the screw pile (allowing for installation and design loads)
- durability.

In addition, the Pile Designer shall be responsible for:

- designing all secondary elements, such as the connection between the screw pile stem and the structure
- providing a PS1 Design
- obtaining written acceptance of the PS1 by the local authority
- obtaining a PS2 Design Review and obtaining local authority approval if required by the local authority or Client.

The Pile Designer shall be responsible for undertaking construction monitoring in order to verify that the design meets the requirements of the contract specification and drawings. The Pile Designer shall advise the level of construction monitoring required, produce a PS4 Construction Review, and obtain written acceptance of the PS4 by the local authority.

SP3.0 Extent of work

The work covered by this specification includes the supply of all labour, materials, plant and equipment for the design and construction of screw piles for the contract, all as described in the Drawings and Specification.

SP4.0 Nature of ground

Subsoil investigations have been carried out, and these investigations are contained in the Tender documents. However, no warranty is expressed or implied that such information, given in good faith by the Engineer, will present a complete or accurate picture of the whole of the Site. The Piling Contractor shall be responsible for any inference it may draw from information made available to it.

It is deemed that the Piling Contractor has inspected the Site and considered the nature of the ground through which piles are to be constructed.

The Piling Contractor shall report immediately to the Engineer any circumstances which indicates that in the Piling Contractor's opinion the ground conditions differ from those reported in or which could have been inferred from the geotechnical data provided. The piling Contractor shall be responsible for undertaking additional site investigations as considered necessary to support the screw pile design.

The fact that a tender has been submitted shall be deemed as evidence that the Piling Contractor accepts the full and sole responsibility for the method of working, including the maintenance of excavation stability, the construction of defect-free piles, and positioning the completed piles within the required tolerances to the approximate founding depth specified on the Drawings.

SP5.0 Standard specifications

This Specification shall be read in conjunction with the following Standards, which are deemed to form part of this Specification. In the event of this Specification being at variance with any provision of these Standards, the requirements of this Specification and Drawings take precedence over the provision of the Standard. Reference to any Standard shall include any amendments thereto and any Standard in substitution therefor. All Design, Materials and workmanship shall comply with these Standards unless expressly noted otherwise.

API5L	API Specification for Line Pipe 5L
AS 1163	Structural Steel Hollow Sections
AS 2159	Piling-design and Installation
AS/NZS 1170	Loadings Standard
AS/NZS 1554	Welding of steel structures
AS/NZS 4671	Steel Reinforcing Materials
AS/NZS 3678	Structural Steel
NZS 3101	Concrete Structures
NZS 3104	Specification for Concrete Production
NZS 3109	Concrete construction
NZS 3404	Steel Structures
NZS 4711	Qualification tests for metal arc welders

All these documents referenced above shall be the latest revision, complete with current amendments, as at the time of issue of this document for tender.

Other standards or guidelines may include:

- IPENZ Practice Note: Screw Piles
- NZ Building Code Verification Method B1/VM4
- NZ Geotechnical Society Guideline for Field Description of Soil and Rock for Engineering Purposes.

SP6.0 Pile design

Pile design shall be undertaken in accordance with IPENZ Practice Note: Screw Piles and requirements detailed on the Drawings. The design shall be undertaken and verified by a suitably qualified geotechnical or structural Chartered Engineer with experience in the design of screw piles. The piling Contractor shall submit a curriculum vitae for the proposed Pile Designer with his tender.

The design of the structural connection between the pile and the pile cap shall be undertaken in accordance with NZS 3101 Concrete Structures Standard.

Pile design shall consider measures to mitigate the risk of flighting (where the helices do not penetrate and a column of disturbed soil is formed) the auger during installation of the screw pile.

The Pile Designer shall provide a Design Report detailing:

a) Design loads
b) Geotechnical Strength Reduction Factors and supporting methodology
c) Standards
d) Design methodology and how specific loads such as seismic, lateral and settlement are addressed
e) Founding stratum
f) Estimated length
g) Connection from pile to pile cap/slab
h) Pre production and production load testing to support design including acceptance criteria.

SP7.0 Materials

a) Shaft
The shaft shall be:
- Compliant with AS1163 or API 5L standards as required by the project,
- Minimum Grade Steel 350MPa
- Maximum Grade Steel 500MPa
- Minimum Elongation 20%
- Wall Thickness Tolerance 5%

b) Helices
Helices shall be formed from minimum Grade 350 plate compliant with AS/NZS 1365 Structural Steelwork and AS/NZS 3678:2011Structural Steel – Hot-rolled plates, floorplates and slabs.

Helices should be pressed by suitable equipment to ensure a "true helix" is formed to minimise disturbance of the ground during installation and reduce displacement on loading. This requires:
- the pitch at the inside and outside of the helix to be equal (+/- 4% of the helix flange width)
- the gradient of the spiral should be constant
- any radial measurement across the helix should be perpendicular to the shaft (+/-4% of the helix flange width
- Second and third helices shall be positioned on shaft at an exact multiple of pitch
Connection should be in accordance with AS1554.1 Structural Welding – Category SP Weld (plus a minimum level of NDT that is greater or equal than 10%) performed by an AS.NZS 1554.1 qualified welder. The helix shall be fully welded all round, both above and below the helix and seal lead and trail edge.

c) Welds
Weld material shall be 480MPa grade suitable for seismic conditions.

d) Concrete
Concrete infill where applicable shall be a minimum 30MPa produced in accordance with NZS3104.

The Piling Contractor shall provide manufacturer and test certification for all materials.

SP8.0 Handling and storage of piles

All operations such as handling, transporting, lifting and pitching of piles shall be carried out in such a manner as to prevent damage to the piles and/or their coatings.

Piles shall be stacked on suitable supports on firm ground, in a manner which will eliminate excessive handling stresses or other damage.

SP9.0 Method statement

Pre-Production Load Testing (If required)

The Piling Contractor shall provide a method statement for the pre-production load testing. The method statement shall be submitted 2 weeks prior to pile installation for testing and shall contain the following information (as a minimum):

a) Programme of the testing, detailing the timing and sequence of each load test including any additional investigations proposed
b) The general arrangement of the equipment
c) A method for measuring the displacement at the head and toe of each test pile
d) A previous example or template for the Pile Designer's load test report, refer to AS2159: 2009 Appendix A Static Load Test, Section A4 Report
e) Confirming the criteria for determining the acceptability of the load compression and tension load tests
f) A contingency plan in the event that a load test is deemed not acceptable
g) A procedure for verifying the capacity for each individual pile, this may include correlating the installation torque for each pre-production pile with the load test results
h) All pile load tests shall be supervised by suitably experienced personnel, who are competent to operate, monitor and record each test throughout its duration. Each pile load test shall be continuously monitored throughout its duration.

Pile Construction

Each tenderer shall provide a method statement for each piling operation to be undertaken in executing the Works. The method statement shall describe all proposed equipment, and detail the construction sequence. The method statement shall be submitted with the tender and shall contain the following information (as a minimum):

a) Programme of the works, detailing the timing and sequence of individual portions of the works
b) Full details of the installation plant to be used, including manufacturer's information and proof of servicing/recent upkeep and calibration
c) Proposed phasing of excavation/filling operations such that the design stresses in the piles (and any supporting frames) are not exceeded
d) The contingency plan to be adopted, to minimise disruption and delay, in the event of encountering obstructions or where the screw pile helices appear to flight the *in situ* soils
e) Anticipated noise levels (measured in dB) and vibration levels (measured in mm/sec) arising from piling operations (if applicable)
f) The Piling Contractor shall nominate a suitably experienced, professionally qualified engineer, as the "Piling Supervisor". The Piling Contractor shall submit a curriculum vitae for the proposed Piling Supervisor with its tender.

The Engineer's review of the each method statement shall not relieve the Piling Contractor or the Pile Designer of its obligations to meet the requirements of this Specification.

SP10.0 Setting out and as-built locations

The position of all piles shall be accurately set out by the Piling Contractor. The pile positions and verticality shall be checked by the Piling Contractor immediately prior to installation.

After construction, actual pile locations and verticality shall be certified by a Chartered Surveyor employed by the Piling Contractor for this purpose. The Piling Contractor shall submit an as-built pile plan to the Engineer, ten days prior to incorporating any piles in to the structure. A partial as-built pile plan can be submitted for each sequence of piling operations, as required. An overall as-built pile plan, showing the as-built locations of all piles, shall be submitted to the Engineer within ten days of completing the last pile.

SP11.0 Supervision

The Piling Supervisor shall be responsible for ensuring that all piling operations comply with the requirements of this Specification, and all referenced publications. The Piling Supervisor shall also ensure that all monitoring and pile records are maintained up to date, and are available for inspection by the Engineer.

SP12.0 Inspection

The Engineer requires the opportunity of observing all phases of the piling operations and of inspecting particular items such as pre-production load testing, installation of the screw piles and construction of the detail to the structure. The Piling Contractor shall therefore keep the Engineer informed daily as to the work anticipated to be carried out on the next working day.

SP13.0 Load testing (compressive and tension)

Load tests to confirm pile design criteria shall be undertaken in accordance with AS 2159: 2009 Appendix A, Static Load Test. Any load test pile shall be sacrificial unless agreed with the Engineer.

The position of each load test shall be agreed on site with the Engineer, prior to commencing installation or erection of the load test equipment.

The load tests shall follow the compression and tension load test procedures outlined in AS2159: 2009 Table A1 and Table A2 respectively. Test loads shall be determined by the Pile Designer in accordance with AS2159: 2009 Table 8.3.3.2 'Test Loads Without Negative Friction'. Test loads shall be calculated on the basis of the maximum serviceability and ultimate limit state loads specified on the Drawings.

The acceptance criteria for compression and tension load tests shall be in accordance with AS2159: 2009 Section 8.4.3, Table 8.4.3.1 with the following variation where approved by the Engineer:

- For compression proof testing amending the pile settlement criteria to 10% of the pile diameter (where piles are greater than 500mm dia) to determine ultimate geotechnical strength rather than that detailed in AS2159 Table 8.4.3.1.

SP14.0 Tolerances

The Piling Contractor shall make all necessary provisions to the drilling procedure, installation, initial spotting and inclination of piles in order to achieve installation of piles to the specified tolerances as set out in the Drawings. A starting point is to refer to positional tolerances as set out in [1] Section 7.2.1.

If records or measurements show that piles have been installed outside the specified tolerances, the Piling Contractor shall provide the Engineer with details of measures to be adopted to enable the piles to comply with the specification. Forcible correction of laterally displaced piles shall not be made, unless the Piling Contractor can demonstrate that the strength, integrity and durability performance of the pile will not be adversely affected.

Should the Piling Contractor fail to meet the above requirements, the Engineer reserves the right to order such extra work as may be required to overcome the resultant structural problems.

The Piling Contractor shall not carry out remedial work on any pile, without the written approval of the Engineer.

SP15.0 Pile construction record cards

The Piling Contractor shall complete a Pile Construction Records for every pile constructed on the Site. A copy of the proposed Pile Construction Record Card shall be submitted to the Engineer on the week prior to commencing pile construction. The Pile Construction Record Card shall contain the following information as a minimum:

a) Contract Structure and Name
b) Pile number, location, pile type and pile dimensions, installation date
c) Details of any predrilling or other preparatory works
d) ULS load requirement
e) Profile of installation torque or pressure with depth and design torque if provided
f) Power head and excavator used
g) The expected and actual founding levels
h) Pile head position in relation to design
i) Inclination
j) Concrete/grouting records
k) Design and actual constructed elevation of the top of the pile
l) Piling contractors signature verifying that all the work has been completed satisfactorily

Pile construction records shall be submitted to the Engineer within 48 hours of the completion of each pile.

SP16.0 Protection of existing structures

The Piling Contractor shall take all care to ensure that no damage is caused by any of the piling works to any existing structure, property or services, and shall undertake to make good, at his expense, any damage caused through vibration, excavation or undermining. If the Piling Contractor suspects that the piling operation, at any stage, may cause any damage to existing structures, property or services, he shall notify the Engineer immediately.

SP17.0 Protection of adjacent property

The Piling Contractor shall take all reasonable precautions to avoid damage to adjoining public and private property, and shall undertake to make good, at his expense, any damage caused through vibration, excavation or undermining.

SP18.0 Completion

On completion, the Piling Contractor shall leave the Site and the Contract Works clean and ready for immediate use by following contractors.

Appendix D
Screw Pile Shaft Specification and Design

D.1 Hollow section specifications

Specifications for circular hollow sections which are currently available (such as *AS 1163 Structural Steel Hollow Sections*) generally target either a circumferential design capacity basis, or a longitudinal design basis. The former is for liquids transportation and/or a pressure vessel/distribution system, while the latter is primarily for structural members. Neither pay particular attention to torsional capacity, nor is weld seam integrity adequately addressed. Furthermore, considerable variation exists in terms of allowable wall thicknesses,such that a Circular Hollow Section (CHS) product may be within specification, but significantly below the capacity expectation of the designer.

It is for this reason, and from experience of those involved with screw piling operations, that the API 5L standard is strongly recommended.

For product specifications:

- With AS 1163, the yield strength relates to longitudinal yield, while in API 5L it is typically the circumferential yield value. The designer needs to use the appropriate parameter for the design aspect under consideration
- With AS 1163, the seam weld is generally Electric Resistance Welded (ERW). Past failures in screw piles during installation have most often been attributed to weld failures. It is widely accepted that improved testing of weld integrity would be beneficial
- Products that comply to API 5L may use one of a number of welding processes. This standard has higher testing requirements, including the weld. where every pipe is hydrostatically tested, albeit to a percentage of yield
- Manufacturer and test certification should be required
- If the designer insists on using product to AS 1163, additional testing and/or weld enhancement measures should be considered.

D.2 Steel feedstock

Minimum Grade of Feedstock
Specifying a feedstock grade equal to that of the end product yield strength, e.g. 350 MPa feedstock is recommended. Quality control from the steel make process is generally quite high, and considerably higher than reliance on the potentially variable strength gain from the cold rolling process.

Maximum Grade
Setting a maximum yield of, say 500 MPa, ensures the product will be closer to the more standard carbon steel mixture, rather than a higher specified steel which includes higher trace element contents. This also affects weld ability aspect.

Elongation Requirements
Setting a minimum 20% elongation requirement will ensure a more ductile and robust product. In addition to seismic performance aspects, product meeting this criteria is generally considered to be tougher and therefore more robust for the critical installation phase.

Wall thickness tolerance
Specification of a reduced undersize tolerance, e.g. 5%, will ensure that the final product is satisfactorily close to the capacity expected by the designer. Some standards allow up to 10% undersize or even more, which means that this criteria alone can more than negate the intention of the material capacity reduction factor, phi – yet still be within specifications.

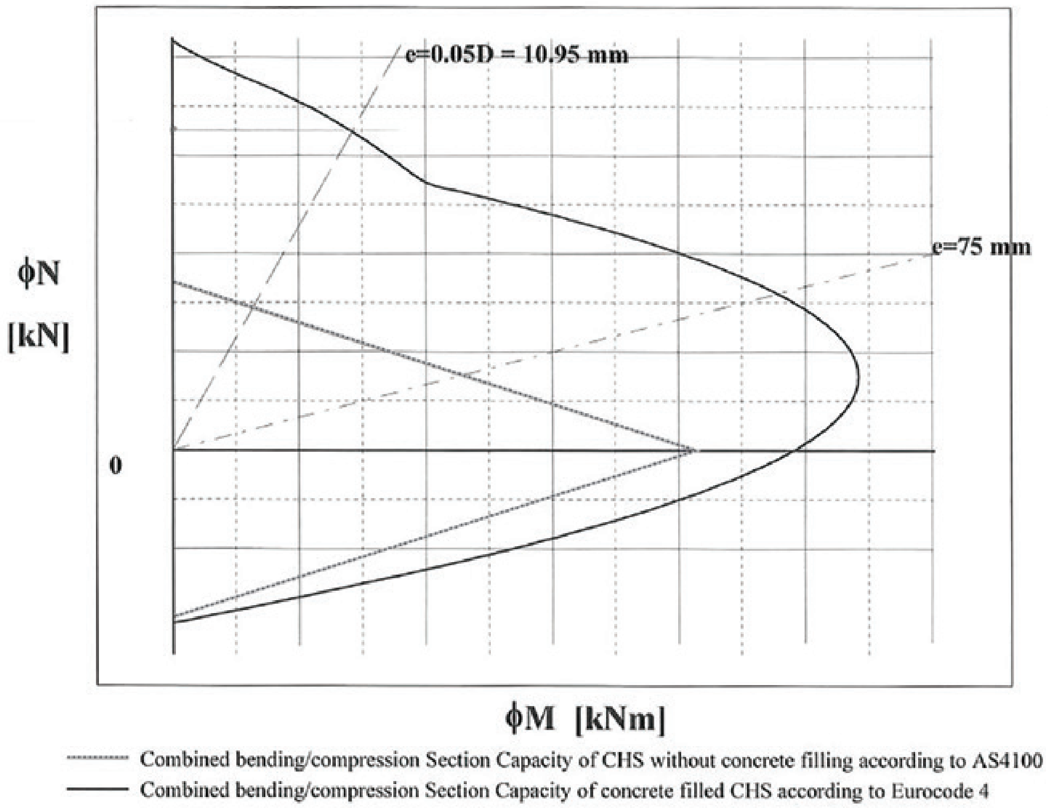
D.3 Screw pile shaft design

A sample moment-axial capacity chart is presented below in Figure D.3 for the design of screw pile capacity considering both installation as well as long term loading.

The chart illustrates the inter-dependance of several key design factors including:

- Installation capacity is typically on the unfilled, i.e. steel only, section
- Available moment capacity (ϕM) is influenced by axial load (ϕN)
- Allowance must be made for long term corrosion effects. This will typically mean a reduction in wall thickness, especially for external corrosion
- Allowance must be made for eccentricity of loading, taking account of construction tolerances, pile connection, superstructure
- Time allowance should be made for the concrete infill to achieve sufficient strength – and stiffness, subsequent to the filling process.

Figure D.3.1: Sample M-N Curve



Appendix E
Example Screw Pile Record Card

SCREW PILE RECORD CARD

Contract:								
Job No:			**Date:**		**Revision:**		**Signed:**	
Pile #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ULS Comp. load required:								
ULS Tension load required:								
Shaft x Wall:								
Helix:								
Expected Depth:								
Powerhead:								
Excavator:								
Final Torque reqd:								
Ave.Torque reqd over last 2m:								
Install to Torque:								
Max Torque Not to Be Exceeded								
Depth Not to be Exceeded								
Operator/Groundsman:								
Offset North +ve:								
Offset East +ve:								
Inclination								
RL Top of Pile								
Concrete Infill and Volume								
Date **starter** installed:								
Date **extension 1** installed:								
Date **extension 2** installed:								
Sign Off:								
Comments:								

DISCLAIMER

While the authors have made every effort to present a carefully considered Practice Note based on their own professional practice, as well as consultation with the wider industry and the sponsors, they accept that what constitutes good practice may alter over time following changes in knowledge, technology and legislation. The authors also acknowledge that differing interpretations of relevant legislation and regulations are possible and that each practitioner will need to confirm requirements with the relevant authorities.

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